Influence of environmental factors on the spatial distribution and diversity of forest soil in Latvia

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Received 22 June 2011, accepted 4 November 2011

Abstract. This study was carried out to determine the spatial relationships between environmental factors (Quaternary deposits, topographical situation, land cover, forest site types, tree species, soil texture) and soil groups, and their prefix qualifiers (according to the international Food and Agricultural Organization soil classification system World Reference Base for Soil Resources [FAO WRB]). The results show that it is possible to establish relationships between the distribution of environmental factors and soil groups by applying the generalized linear models in data statistical analysis, using the *R 2.11.1* software for processing data from 113 sampling plots throughout the forest territory of Latvia.

A very high diversity of soil groups in a relatively similar geological structure was revealed. For various reasons there is not always close relationship between the soil group, their prefix qualifiers and Quaternary deposits, as well as between forest site types, the dominant tree species and specific soil group and its prefix qualifiers. Close correlation was established between Quaternary deposits, forest site types, dominant tree species and soil groups within nutrient-poor sediments and very rich deposits containing free carbonates. No significant relationship was detected between the *CORINE Land Cover 2005* classes, topographical situation and soil group.

Key words: Quaternary deposits, forest type, FAO WRB classification, generalized linear models.

INTRODUCTION

In recent decades soil scientists have turned their attention to soil diversity research and measurement to analyse spatial patterns (McBratney & Minasny 2007; Minasny et al. 2010). Furthermore, there has been increasing research into the optimization of obtaining and use of soil information according to secondary data of environmental parameters (topography, geology, soil, land cover) in the world (Grimm & Behrens 2010). The environmental factors determine soil-forming processes and soil development, e.g. humus accumulation, podzolization, lessivage and gleyzation. The time of interaction of these processes is very diverse within various environmental conditions and determines soil diversity (Phillips & Marion 2004; Targulian & Krasilnikov 2007). In order to determine the influence of environmental factors on soil genesis (Jenny 1941; Bockheim 2005), soil-forming processes (Targulian & Krasilnikov 2007) and development, the spatial distribution of soil cover has been widely and protractedly studied (McBratney 1992, 1998; Burrough 1993; Ibañez et al. 1995, 1998; Burrough et al. 1997; Ibañez & De-Alba 2000; Guo et al. 2003; Phillips & Marion 2004, 2005; Bockheim et al. 2005; Saldaña & Ibáñez 2007; Uuemaa et al. 2008; Gray et al. 2009). Such research is necessary because incomplete knowledge about environmental conditions may sometimes lead to the overestimation of soil-forming processes and cause problems in the application and comparison of soil classifications (Reintam 2002).

Still, the investigation and distinguishing of soil-forming factors pose problems related to the examination of relationships and interpretation of results according to different soil classifications. As a result, soil scientists have so far not reached an agreement on the influence of various environmental conditions on the spatial distribution of soil in regional and local aspects (Gray et al. 2009).

Despite the increasing demand for soil data, the cost and time required for traditional soil mapping mean that often they are not available; therefore, digital soil mapping technologies (Dobos et al. 2006) have been developed to provide fast and accurate methods to predict soil variables spatially (Grimm & Behrens 2010). Digital soil mapping depends on statistical relationships between measured soil observations and environmental covariates in sample locations. If there is an error in sample locations, it will spread to the inferred relationships and soil observations and covariates will not actually correspond (Cressie & Kornak 2003). Another source of error in inferred relationships stems from spatial uncertainty in environmental predictors used for digital soil mapping, which are often of varying provenance, age, scale, resolution, mapping scheme and/or aggregation level (Bishop et al. 2006; Grimm & Behrens 2010).

Thus, the study of relationships between soil and environmental factors strengthens the knowledge about soil distribution rules (Bui & Moran 2001). The inclusion of these rules into the mapping procedure and modelling improves spatial prediction and allows extrapolation of data from reference areas to a wider scale (Lagacherie et al. 2001).

At the same time McBratney et al. (2003) have observed that it is difficult to find studies in which relationships between different soil-forming factors and multivariate functions are clearly described. In addition, it is hard to make correct predictions of soil properties at each point of the landscape due to high spatial diversity of these properties (Burrough et al. 1997). For these reasons finding relationships between soil-forming factors and variables in soil maps is one of the largest problems in soil surveys. Although research into factors determining the spatial distribution of soil has been conducted in different regions of the world, statistically reliable information is lacking on soil distribution patterns in the boreo-nemorial region, where soils have developed mainly on the Late Weichselian glacial deposits that have been variously altered by postglacial aeolian, marine, lacustrine or fluvial processes and in about 10% of the territory are overlain by mires (Karklins et al. 2009; Zelčs et al. 2011).

This study aims to find out the relationship between environmental factors (geological structure, topographical situation, land cover, forest site types, tree species, soil texture) and soil groups and their prefix qualifiers determined according to the international World Reference Base (WRB) for Soil Resources in Latvia. The fact that the aforementioned classification has thus far not been used in the mapping of Latvian soils adds to the relevance of the study.

MATERIALS AND METHODS

Study area

Latvia is located in the Northeastern part of Europe (Fig. 1), within the boreo-nemorial region, where coniferous forests are mixed with broad-leaved species (Hytteborn et al. 2005).

The climate of Latvia is moderate. The average annual precipitation is 700–800 mm, of which about 500 mm falls in the warm period. The mean annual temperature is +5.5 °C. Soils have developed mainly on Late Weichselian glacial deposits (loamy sand, sandy clay, loam, clay, gravel, sand), altered to some extent by postglacial aeolian, marine, lacustrine, alluvial and mire sediments (Zelčs et al. 2011).

Forests cover 3.53 million hectares or 54.7% of the country's territory (Latvijas Statistika 2010). Forest stands mainly consist of three tree species, Scots pine (*Pinus sylvestris* L.), Norway spruce (*Picea abies* [L] *Karst.*) and birch (*Betula* L. spp.), which take up 74% of the whole of the forest area.

Data material and methodology of investigations

From 2006 till 2011, under the international project 'Inventarization of forest soils and assessment of forest biological diversity "BioSoil"' of the Focus Forest research programme of the International Co-operative Programme (ICP) and forest monitoring, investigations were carried out on 95 sampling plots of ICP Forest monitoring and in 18 sampling plots within relatively poorly represented regions of this monitoring by digging deep soil profiles and soil profile description according to the international WRB soil classification (IUSS Working Group WRB 2007). The soil samples were collected from soil profile diagnostic horizons, and physical and chemical analyses were done in the laboratory according to the methodology of ICP Forest monitoring (United Nations 2006).

The field works were carried out to determine site topography (United Nations 2006), parent material – Quaternary deposits and pre-Quaternary sedimentary rock, the dominant tree species of the forest stand and forest site types in the sampling plots. Land cover was described by using data from *CORINE Land Cover 2005*, which characterize (bio)physical cover of the earth surface at a scale of 1 : 100 000. Forests in Latvia fall into three classes according to *CORINE Land Cover 2005*: deciduous forests (11 sampling plots), coniferous forests (47 sampling plots) and mixed forest (55 sampling plots). Quaternary deposits were analysed, taking into account their granulometric composition and occurrence in surface topography.

The forest site types were described according to the Latvian forest ecosystem classification (Bušs 1997), which was originally developed in the early 1900s based on Braun-Blanquet methods and subsequently modified, taking into account forest typology based on forest management and ecology (Bušs 1987). The described forest site types, divided into five major groups, have been determined by stand productivity and ecological and biological attributes (Bušs 1997). Three major groups of natural forest ecosystems defined by the water regime are recognized (although they differ in the trophic level): upland dry forests, wet mineral soil forests and

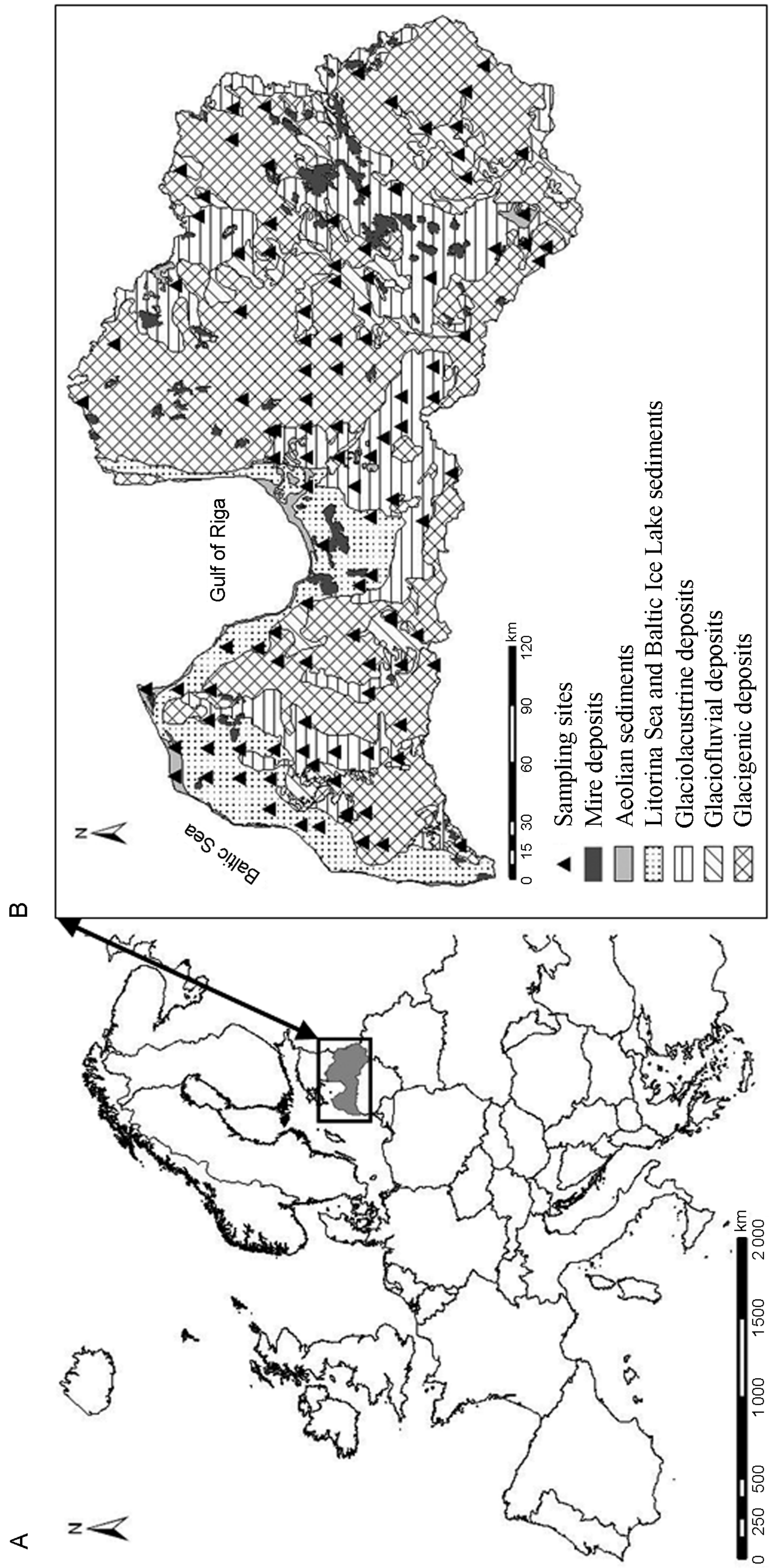

Fig. 1. A, location of the study area; **B**, sampling sites and Quaternary surface deposits in Latvia (after Geological map of Latvia 1981).

forests on wet peat soil. Due to the large areas of drained forests in Latvia, in the typology these forests are treated as two separate groups: forests on drained mineral soil and drained forests on peat soil. Each of these five major groups is further subdivided into forest site types on the basis of their position along nutrient and species composition gradients (Bušs 1997).

A generalized linear model analysis, using the *R 2.11.1* software, was carried out to investigate the relationships (the level of significance $p < 0.05$) between soil spatial distribution and parent material, topographical situation, land cover, soil texture, forest site type and tree species. Akaike's An Information Criterion (AIC) is a generalized information criterion for a fitted parametric model (Sakamoto et al. 1986). Lower AIC values better describe fitting generalized linear models. Each type of factors was defined by the quantitative value of occurrence (0 – not observed, 1 – observed) in the sampling plots to clarify the influence of different Quaternary deposits, topographical situation, land cover and forest site type on the spatial distribution of soil. Nelder & Wedderburn (1972) gradually introduced and McCullagh & Nelder (1989) further developed the use of generalized linear models for statistical processing of data, which are also used in this study, because they allow us to process other types of data distribution besides normal (Quinn & Keough 2002) and do not cause problems with non-normal error terms, so that it is possible to avoid situations when data transformations are not effective in making errors normal (e.g., when the response variable is categorical). Corrections of p-values were performed by Hommel's adjustment method (Hommel 1988). This method is valid when the hypothesis tests are independent or when they are non-negatively associated (Sarkar & Chang 1997; Sarkar 1998). The adjustment methods include the Bonferroni correction (bonferroni) in which the p-values are multiplied by the number of comparisons. Variables (soil groups – Phaeozems, Umbrisols; geological sediments – Litorina Sea, Alluvial sediments; forest site types – *Vaccinioso-sphagnosa*, *Sphagnosa*, *Caricoso-phragmitosa*, *Vacciniosa turf. mel* and *Vacciniosa mel.*) occurring in less than three sampling plots were not included in p-value adjustment.

Quantitative values (1–100%) of tree species in forest stands and soil texture were used to confirm the relationships between the spatial distribution of soils and Quaternary deposits.

Relationships between soil sampling plots (80) and soil texture (top and bottom: sand, silt, clay) were determined, using principal component analysis (PCA).[1] A Monte Carlo test was used to test the significance of the PCA axes. Pearson correlation coefficients were determined between environmental factors and PCA scores for samples.

RESULTS

In Latvia, forests are situated on soils of relatively high diversity, formed on different, mainly unconsolidated Quaternary deposits, in some places, also on weakly consolidated pre-Quaternary terrigenous or hard carbonate sedimentary rock (Table 1). In total, soils of high spatial diversity cover a relatively larger area and are developed

Table 1. Occurrence of soil groups (IUSS Working Group WRB 2007) in sampling plots within the areas of Quaternary deposits

Types of Quaternary deposits (n)	Soil groups (n)										
	Histosols (16)	Gleysols (8)	Podzols (9)	Planosols (10)	Stagnosols (12)	Phaeozems (2)	Albeluvisols (9)	Luvisols (14)	Umbrisols (2)	Arenosols (25)	Cambisols (6)
Aeolian dunes (7)	–	–	1	–	–	–	–	–	–	6	–
Litorina Sea (2)	–	–	1	–	1	–	–	–	–	–	–
Baltic Ice Lake (9)	–	1	4	–	–	–	–	–	1	3	–
Alluvial (1)	–	–	–	–	–	–	–	–	–	1	–
Glaciofluvial (20)	–	–	2	3	1	–	1	–	1	12	–
Glaciolacustrine (27)	–	5	1	6	5	2	1	4	–	3	–
Glacigenic (31)	–	2	–	1	5	–	7	10	–	–	6
Organic (16)	16	–	–	–	–	–	–	–	–	–	–

n, number in sampling plots; – not found.

[1] PCA software *PC ORD 5.10*.

on top of glacigenic (31 sampling plots), glaciolacustrine (27 sampling plots) or glaciofluvial (20 sampling plots) deposits and sediments from different stages of the Baltic Sea (11 sampling plots) (Table 1). From the viewpoint of soil diversity, aeolian dune sediments (7 sampling plots), where Arenosols (6 sampling plots) and Podzols (1 sampling plot) are common, are relatively homogeneous (Table 1). Histosols are common on organic deposits (16 sampling plots).

The diversity of soils is greatest on glacigenic and glaciolacustrine deposits, with the highest variety in granulometric composition (sand, loamy sand, loam, silt, clay). Luvisols (10 sampling plots), Albeluvisols (7 sampling plots), Cambisols (6 sampling plots) and Stagnosols (5 sampling plots) occur most frequently in the areas of glacigenic deposits, while in glaciolacustrine deposits Planosols (6 sampling plots), Stagnosols (5 sampling plots), Gleysols (5 sampling plots) and Luvisols (4 sampling plots) are mainly distributed (Table 1).

Using a generalized linear model, on the basis of analysis of the obtained data, it was established (Table 2) that the prevalence of a soil group is closely linked to specific parent material. A significant relationship ($p < 0.05$) of spatial distribution exists between the Baltic Ice Lake sediments and Podzols; glaciofluvial deposits, aeolian sediments and Arenosols; organic deposits and Histosols; and glacigenic deposits and Cambisols, Luvisols and Albeluvisols. Gleysols and Planosols are closely associated with glaciolacustrine deposits. Furthermore, the spatial distribution of Stagnosols is not linked to specific parent material, but they occur most frequently in glaciolacustrine and glacigenic deposits, where the parent material has a relatively heavy soil texture.

When specifying the main groups of particular soils and their prefix qualifier relationships with plots in geological structures, a significant relationship ($p < 0.05$) to the Quaternary deposits was generally established for a part of the soil groups (Table 3). Albic Arenosols occur most frequently in aeolian dunes and glaciofluvial sand and gravel sediments (Table 3). These sediments have a relatively low cation exchange capacity (CEC = 2.8–10.4 $cmol_c\ kg^{-1}$), which promotes the process of podzolization and development of the Albic horizon.

Owing to the flat surface topography with disturbed natural drainage in the area, there is a significant relationship ($p < 0.05$) between the spatial distribution of the Baltic Ice Lake sands and the occurrence of Endogleyic Histic Podzols (Table 3). Endogleyic Arenosols are commonly found in sandy plains of the Baltic Ice Lake.

Albic Podzols, however, are not linked to specific parent material and occur in various sediments of different genesis, where sandy parent material is distributed. Furthermore, the spatial distribution of Calcic Endostagnic Endogleyic Cutanic Luvisols, Stagnic Cutanic Albeluvisols and Stagnic Cambisols is closely related to glacigenic deposits. Surface water filtration is disturbed in tills, where the subsoil has a relatively heavy soil texture (loam, silt loam, clay loam and clay), resulting in a stagnic and gleyic colour pattern that morphologically indicates Stagnic and Endogleyic prefix qualifiers.

Table 2. Relationships between Quaternary deposits and soil groups (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Types of Quaternary deposits (*n*)		Soil groups (*n*)								
		Histosols (16)	Gleysols (8)	Podzols (8)	Planosols (10)	Stagnosols (11)	Albeluvisols (9)	Luvisols (14)	Arenosols (24)	Cambisols (6)
Aeolian	AIC	–	–	66	–	–	–	–	109	–
(7)	*p*	–	–	0.71	–	–	–	–	**0.006**	–
Baltic Ice Lake	AIC	–	62	56	–	–	–	–	123	–
(8)	*p*	–	0.87	**0.002**	–	–	–	–	0.40	–
Glaciofluvial	AIC	–	–	67	71	80	66	–	106	–
(19)	*p*	–	–	0.71	0.29	0.38	0.59	–	**0.0004**	–
Glaciolacustrine	AIC	–	56	66	65	78	66	88	121	–
(25)	*p*	–	**0.03**	0.71	**0.03**	0.37	0.59	0.66	0.24	–
Glacigenic	AIC	–	62	–	70	78	56	75	–	34
(31)	*p*	–	0.87	–	0.29	0.38	**0.009**	**0.001**	–	*
Organic	AIC	4	–	–	–	–	–	–	–	–
(16)	*p*	*	–	–	–	–	–	–	–	–

n, number in sampling plots; – not found; * occurrence of soil groups only within specific Quaternary deposits.

Table 3. Relationships between Quaternary deposits and soil groups with prefix qualifiers (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Types of Quaternary deposits (*n*)		Soil groups with prefix qualifiers (*n*)									
		Albic Arenosols (12)	Endogleyic Arenosols (5)	Ferralic Arenosols (6)	Hypoferralic Arenosols (5)	Rubic Arenosols (10)	Albic Podzols (6)	Histic Podzols (4)	Endogleyic Podzols (3)	Endogleyic Planosols (8)	Luvic Planosols (6)
Aeolian	AIC	69	–	56	44	69	56	–	–	–	–
(7)	*p*	**0.0004**	–	0.37	0.44	0.24	0.54	–	–	–	–
Baltic Ice Lake	AIC	85	41	54	–	72	54	35	27	–	–
(8)	*p*	0.97	0.06	0.15	–	0.80	0.24	**0.002**	*	–	–
Glaciofluvial	AIC	81	45	54	41	62	56	–	–	60	50
(19)	*p*	0.18	0.93	0.20	0.09	**0.004**	0.54	–	–	0.32	0.57
Glaciolacustrine	AIC	82	44	–	45	70	56	45	–	59	49
(25)	*p*	0.34	0.78	–	0.83	0.60	0.54	0.83	–	0.24	0.42
Glacigenic	AIC	–	–	–	–	–	–	–	–	61	51
(31)	*p*	–	–	–	–	–	–	–	–	0.36	0.57

Types of Quaternary deposits (*n*)		Soil groups with prefix qualifiers (*n*)										
		Stagnic Cambisols (4)	Endogleyic Stagnosols (6)	Luvic Stagnosols (5)	Calcic Stagnosols (6)	Luvic Gleysols (6)	Stagnic Albeluvisols (4)	Cutanic Albeluvisols (7)	Endogleyic Luvisols (6)	Cutanic Luvisols (7)	Calcic Luvisols (7)	Endostagnic Luvisols (4)
Aeolian	AIC	–	–	–	–	–	–	–	–	–	–	–
(7)	*p*	–	–	–	–	–	–	–	–	–	–	–
Baltic Ice Lake	AIC	–	–	–	–	51	–	–	–	–	–	–
(8)	*p*	–	–	–	–	0.70	–	–	–	–	–	–
Glaciofluvial	AIC	–	–	45	–	–	–	56	–	–	–	–
(19)	*p*	–	–	0.93	–	–	–	0.76	–	–	–	–
Glaciolacustrine	AIC	–	49	39	49	49	–	–	51	56	56	–
(25)	*p*	–	0.19	0.78	0.19	0.42	–	–	0.67	0.76	0.76	–
Glacigenic	AIC	28	49	45	49	51	28	45	42	50	50	28
(31)	*p*	*	0.19	0.93	0.19	0.70	*	**0.01**	**0.02**	**0.02**	**0.02**	*

n, number in sampling plots; – not found; * occurrence of soil groups with prefix qualifiers only within specific Quaternary deposits.

Although most soil groups (Gleysols and Planosols) are closely related to glaciolacustrine deposits, no significant correlation between these deposits and soil prefix qualifiers was established.

The study results show that soil texture is the most important factor determining the forest soil diversity in the Late Weichselian glacial deposits and Holocene aeolian, marine, lacustrine, alluvial and mire sediments. The occurrence of Arenosols and Podzols is mostly related to sandy sediments. The existence of other soil groups is not so closely related to the dominance of a particular fraction of soil texture; rather, it depends on such factors as different drainage conditions and texture in soil horizons. Principal components analysis clearly shows the role of soil texture in the spatial distribution of certain groups of soil. The PCA ordination of soil profiles extracted two principal components which together accounted for 85.60% of the total variation (Fig. 2). However, only the first axis, which explained 75.91% of the total variation, was statistically significant ($p < 0.05$).

The sample scores on the first axis were positively correlated with the top and bottom sand contents ($r = 0.78$, $r = 0.97$). The silt ($r = -0.86$) and clay ($r = -0.85$, $r = -0.92$) contents in the top and bottom of soil profiles were negatively correlated with this gradient. This suggests that a soil texture characterized by a higher sand content provides more favourable conditions for the development of Arenosols and Podzols.

Forest monitoring soil sampling plots were established in 16 of the 23 forest site types distributed in Latvia. Sixty-seven profiles of the 113 studied sampling plots were located in forest site types on dry mineral soil. There, the most common soils were Arenosols (24 sampling plots),

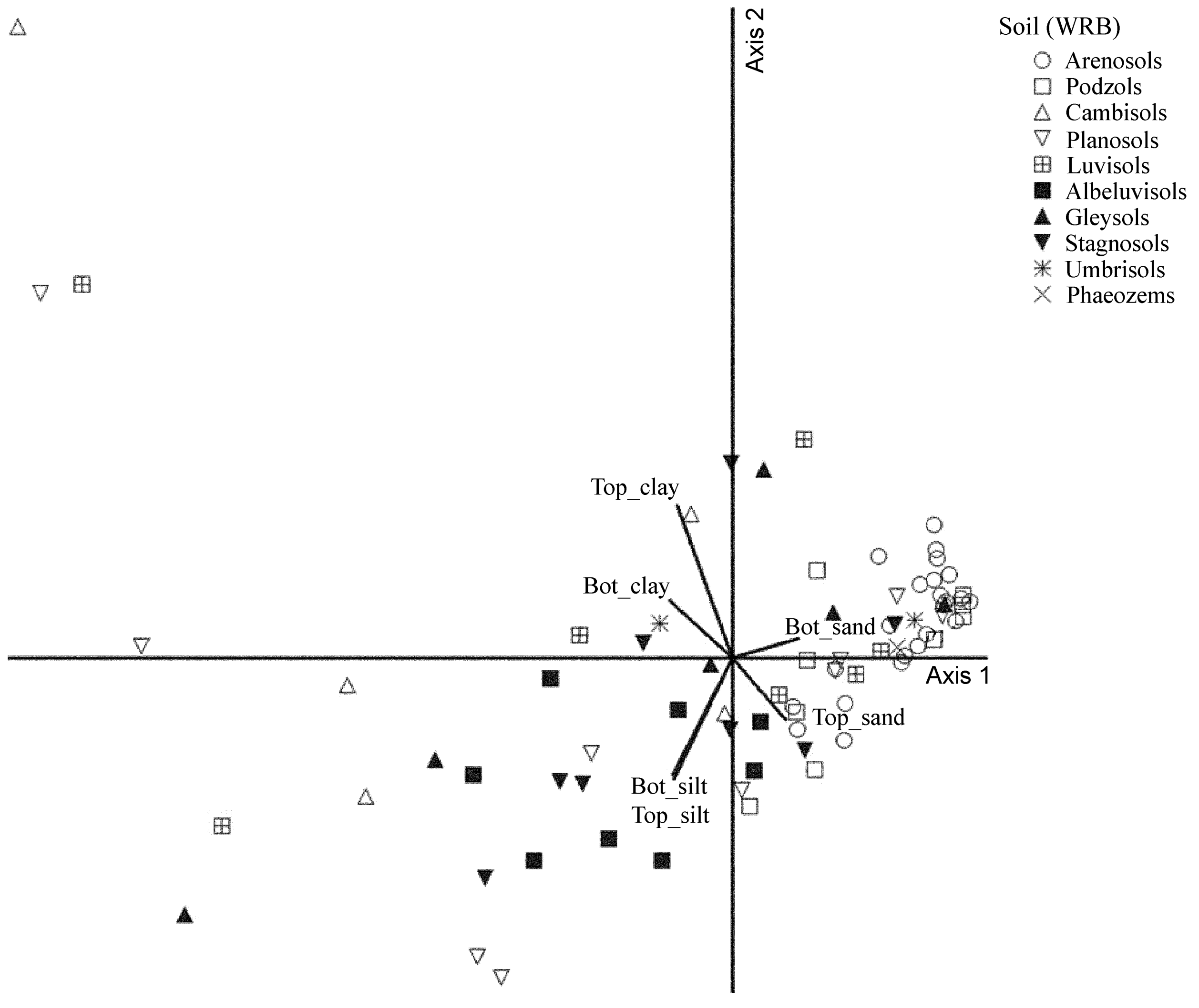

Fig. 2. The PCA ordination of the mineral soil sampling plots based on soil texture in the top and bottom of the soil profile (Top_clay – % of clay in the top; Top_silt – % of silt in the top; Top_sand – % of sand in the top; Bot_clay – % of clay in the bottom; Bot_silt – % of silt in the bottom; Bot_sand – % of sand in the bottom).

Luvisols (13 sampling plots), Albeluvisols (9 sampling plots), Podzols (6 sampling plots), Planosols (5 sampling plots) and Stagnosols (4 sampling plots) (Table 4), while Cambisols (3 sampling plots), Phaeozems (2 sampling plots) and Umbrisols (1 sampling plot) occurred less frequently. Eleven sampling plots were located in forest site types on wet mineral soil, where the following soils were found (in accordance with the FAO WRB soil classification): Stagnosols, Cambisols, Planosols, Gleysols, Podzols and Arenosols. In forest site types on drained mineral soil (19 sampling plots), in most cases one could find the same soils as in the forest types on wet mineral soil, whereas Luvisols, Umbrisols and Cambisols were detected in addition in 3 sampling plots. Furthermore, 4 forest site types on wet peat soil and 12 forest site types on drained peat soil were prevalent in Histosols (Table 4). Due to the fact that the determination criteria (thickness of the peat layer) for Histosols forest site types on peat soil and drained peat soil are similar, the incidence of the aforementioned forest site types fully corresponded to that of Histosols.

Although several forest site types were related to most soil groups, only in some cases there was a significant relationship ($p < 0.05$) between the spatial distributions of soil groups and forest site types, e.g. Albeluvisols and *Hylocomiosa*; Arenosols and *Vacciniosa*; Stagnosols and *Myrtilloso-polytrichosa*; Gleysols and *Mercurialiosa mel.* and *Myrtillosa mel.*; Luvisols and *Aegopodiosa* (Tables 5, 6). *Cladinoso-callunosa* and *Myrtillosa* are common only on Arenosols within the studied sampling sites. The spatial distribution of *Myrtilloso-polytrichosa* is close to significant relationship with Cambisols, while *Aegopodiosa* is near to close relationship with Stagnosols. However, no significant correlation of certain forest site types with Podzols and Planosols was established, because it occurs relatively equally often within forest site types on dry and wet mineral soil and drained mineral soil.

The usage of the prefix qualifier of soil groups in data processing enabled us to define more precisely the significant relationships between some particular distribution of site types of forests and soils (Tables 7, 8). The statistical analysis of generalized linear models also enabled us to specify the significant relationship ($p < 0.05$) between site types of forests and Arenosols. Albic Arenosols are found mostly in aeolian dunes, where the *Vacciniosa* and *Myrtillosa* forest site types are common. Endogleyic Arenosols have been formed mostly in the sandy plains of the Baltic Ice Lake, where the *Myrtillosa* forest site type is spread. Rubic Hypoferralic Arenosols have been formed in the glaciofluvial deposits, hosting the *Vacciniosa* and *Myrtillosa* forest site types. Furthermore, there was a significant relationship ($p < 0.05$) between the spatial distribution of Endogleyic Endostagnic Calcic Luvisols and glacigenic deposits, where the *Aegopodiosa* forest site type is common. At the same time, independently of geological deposits, significant correlation between Endogleyic Calcic Luvic Stagnosols and the *Aegopodiosa* spatial distribution was found. However, in this case no significant relationship between the forest site types on dry mineral soil *Oxalidosa*, *Hylocomiosa* and prefix qualifiers of soil groups was established.

A significant relationship ($p < 0.05$) was established between Cutanic Albeluvisols, Calcic Endogleyic Cutanic Luvisols and glacigenic deposits that are found in poorly drained mineral soils of relatively heavy soil texture. Endostagnic Luvisols, Stagnic Cambisols and Stagnic Albeluvisols are distributed on glacigenic deposits.

The *Myrtilloso-polytrichosa* forest site type is common within Endogleyic Stagnosols, Luvic Gleysols, Endogleyic Planosols and Stagnic Cambisols. However, in this case no significant relationship between *Myrtilloso-polytrichosa* and soil prefix qualifiers was established.

A significant relationship ($p < 0.05$) was determined between the forest site type on drained mineral soil *Mercurialiosa mel.* and Luvic Gleysols. In this case, however, no significant correlation between *Myrtillosa mel.* forest site type and prefix qualifiers of soil groups was established.

The study results showed that, in general, the spatial distribution of forest site types is not determined by soil groups, except dry forest ecosystems, where *Cladinoso-callunosa*, *Vacciniosa* and *Myrtillosa* are closely related to Arenosols, *Hylocomiosa* to Albeluvisols, *Aegopodiosa* to Luvisols, and all of the investigated forest site types on wet and drained peat soil are related to Histosols. Assessing the correlation between the soil group prefix qualifiers and forest site types, in most cases within dry mineral soil, we detected a significant relationship between a specific soil group and *Vacciniosa*, *Myrtillosa* and Aegopodiosa (Table 7).

As a result of the study, we found that the distribution of the dominant tree species in a forest site stand is relatively less associated with a particular soil group, compared to the forest site type and soil group occurrence. The dominant tree species in the forest stands of the forest ecosystems of Latvia, such as pine, spruce and birch, are found on all of the studied groups of soils (Table 9). In the sampling sites, pine is common on Arenosols (32.8% of cases), Histosols (16.4%) and Podzols (11.9%). Spruce stands are mainly distributed on Luvisols (14.4%), Histosols (13.0%), Stagnosols (13.0%), Planosols (13.0%) and Arenosols (11.59%), and birch stands on Histosols (18.8%), Stagnosols (15.0%) and Planosols (15.0%). In Latvia, oak stands occur mostly on Luvisols (33.3%). A similar spatial distribution is characteristic of aspen stands. Other tree species

Table 4. Occurrence of forest site types in sampling plots within different soil groups (IUSS Working Group WRB 2007)

Soil groups (*n*)	Forest site types															
	On dry mineral soil (*n*)						On wet mineral soil (*n*)		On wet peat soil (*n*)		On drained mineral soil (*n*)			On drained peat soil (*n*)		
	Cladinoso-callunosa (3)	*Vacciniosa* (6)	*Myrtillosa* (6)	*Hylocomiosa* (23)	*Oxalidosa* (14)	*Aegopodiosa* (15)	*Vaccinioso-sphagnosa* (2)	*Myrtilloso-polytrichosa* (9)	*Sphagnosa* (2)	*Caricoso-phragmitosa* (2)	*Vacciniosa mel.* (2)	*Myrtillosa mel.* (13)	*Mercurialiosa mel.* (4)	*Vacciniosa turf. mel.* (1)	*Myrtillosa turf. mel.* (8)	*Oxalidosa turf. mel.* (3)
Histosols (16)	–	–	–	–	–	–	–	–	2	2	–	–	–	1	8	3
Gleysols (8)	–	–	–	–	–	–	–	1	–	–	–	4	3	–	–	–
Podzols (9)	–	1	–	4	1	–	1	–	–	–	1	1	–	–	–	–
Planosols (10)	–	–	–	3	2	–	–	2	–	–	–	3	–	–	–	–
Stagnosols (12)	–	–	–	–	–	4	–	4	–	–	–	3	1	–	–	–
Phaeozems (2)	–	–	–	1	–	1	–	–	–	–	–	–	–	–	–	–
Albeluvisols (9)	–	–	–	5	2	2	–	–	–	–	–	–	–	–	–	–
Luvisols (14)	–	–	–	4	2	7	–	–	–	–	1	–	–	–	–	–
Umbrisols (2)	–	–	–	–	1	–	–	–	–	–	–	1	–	–	–	–
Cambisols (6)	–	–	–	1	2	–	–	2	–	–	–	1	–	–	–	–
Arenosols (25)	3	5	6	5	4	1	1	–	–	–	–	–	–	–	–	–

n, number in sampling plots; – not found.

Table 5. Relationships between the forest site types on mineral and peat soil and soil groups (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Soil groups (*n*)	Forest site types																	
	On dry mineral soil (*n*)												On wet mineral soil (*n*)		On wet peat soil (*n*)			
	Cladinoso-callunosa (3)		*Vacciniosa* (6)		*Myrtillosa* (6)		*Hylocomiosa* (23)		*Oxalidosa* (14)		*Aegopodiosa* (15)		*Myrtilloso-polytrichosa* (9)		*Sphagnosa* (2)		*Caricoso-phragmitosa* (2)	
	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*
Histosols (16)	–	–	–	–	–	–	–	–	–	–	–	–	–	–	16	*	16	*
Gleysols (8)	–	–	–	–	–	–	–	–	–	–	–	–	67	0.62	–	–	–	–
Stagnosols (12)	–	–	–	–	–	–	–	–	–	–	89	0.12	59	**0.01**	–	–	–	–
Podzols (9)	–	–	50	0.43	–	–	115	0.35	89	0.90	–	–	–	–	–	–	–	–
Cambisols (6)	–	–	–	–	–	–	118	0.96	87	0.78	–	–	63	0.09	–	–	–	–
Albeluvisols (9)	–	–	–	–	–	–	112	**0.05**	88	0.90	92	0.41	–	–	–	–	–	–
Luvisols (14)	–	–	–	–	–	–	118	0.96	89	0.90	79	**0.0004**	–	–	–	–	–	–
Planosols (10)	–	–	–	–	–	–	118	0.96	88	0.90	–	–	65	0.32	–	–	–	–
Arenosols (25)	22	*	40	**0.01**	32	*	118	0.96	88	0.90	90	0.30	–	–	–	–	–	–

n, number in sampling plots; – not found; * occurrence of forest site types only within specific soil groups.

Table 6. Relationships between the forest site types on drained mineral and peat soil and soil groups (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Soil groups (*n*)	Forest site types									
	On drained mineral soil (*n*)				On drained peat soil (*n*)					
	Myrtillosa mel. (13)		*Mercurialiosa mel.* (4)		*Vacciniosa turf. mel.* (1)		*Myrtillosa turf. mel.* (8)		*Oxalidosa turf. mel.* (3)	
	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*
Histosols (16)	–	–	–	–	11	*	26	*	19	*
Gleysols (8)	77	**0.01**	26	**0.001**	–	–	–	–	–	–
Stagnosols (12)	83	0.39	38	0.36	–	–	–	–	–	–
Podzols (9)	85	0.97	–	–	–	–	–	–	–	–
Cambisols (6)	85	0.97	–	–	–	–	–	–	–	–
Albeluvisols (9)	–	–	–	–	–	–	–	–	–	–
Luvisols (14)	–	–	–	–	–	–	–	–	–	–
Planosols (10)	82	0.26	–	–	–	–	–	–	–	–
Arenosols (25)	–	–	–	–	–	–	–	–	–	–

n, number in sampling plots; – not found; * occurrence of forest site types only within specific soil groups.

Table 7. Relationships between forest site types on dry mineral soil and soil groups with prefix qualifiers (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Soil groups with prefix qualifiers (*n*)	Forest site types on dry mineral soil (*n*)											
	Cladinoso-callunosa (3)		*Vacciniosa* (6)		*Myrtillosa* (6)		*Hylocomiosa* (23)		*Oxalidosa* (14)		*Aegopodiosa* (15)	
	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*
Albic Arenosols (13)	18	0.99	45	**0.02**	45	**0.009**	115	0.97	88	0.99	–	–
Endogleyic Arenosols (5)	–	–	49	0.30	45	**0.009**	115	0.97	–	–	–	–
Ferralic Arenosols (7)	30	0.25	–	–	41	**0.003**	113	0.97	–	–	–	–
Hypoferralic Arenosols (5)	–	–	38	**0.001**	45	**0.009**	–	–	–	–	–	–
Rubic Arenosols (10)	30	0.34	43	**0.01**	43	**0.009**	115	0.97	89	0.99	–	–
Albic Podzols (7)	–	–	50	0.30	–	–	113	0.97	89	0.99	–	–
Histic Podzols (5)	–	–	–	–	–	–	114	0.97	–	–	–	–
Endogleyic Podzols (4)	–	–	–	–	–	–	113	0.97	–	–	–	–
Endogleyic Planosols (8)	–	–	–	–	–	–	114	0.97	89	0.99	–	–
Luvic Planosols (6)	–	–	–	–	–	–	115	0.97	87	0.99	–	–
Stagnic Cambisols (4)	–	–	–	–	–	–	–	–	85	0.44	–	–
Endogleyic Stagnosols (6)	–	–	–	–	–	–	–	–	–	–	87	**0.04**
Luvic Stagnosols (5)	–	–	–	–	–	–	–	–	–	–	86	**0.03**
Calcic Stagnosols (6)	–	–	–	–	–	–	–	–	–	–	83	**0.006**
Luvic Gleysols (6)	–	–	–	–	–	–	–	–	–	–	–	–
Stagnic Albeluvisols (4)	–	–	–	–	–	–	113	0.97	88	0.99	92	0.49
Cutanic Albeluvisols (7)	–	–	–	–	–	–	113	0.97	87	0.99	91	0.46
Endogleyic Luvisols (6)	–	–	–	–	–	–	115	0.97	89	0.99	83	**0.006**
Cutanic Luvisols (7)	–	–	–	–	–	–	115	0.97	89	0.99	88	0.09
Calcic Luvisols (7)	–	–	–	–	–	–	115	0.97	89	0.99	79	**0.002**
Endostagnic Luvisols (4)	–	–	–	–	–	–	–	–	–	–	75	*

n, number in sampling plots; – not found; * occurrence of forest site types only within a specific soil group.

Table 8. Relationships between forest site types on wet and drained mineral soil and soil groups with prefix qualifiers (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Soil groups with prefix qualifiers (*n*)	Forest site types					
	On wet mineral soil (*n*)		On drained mineral soil (*n*)			
	Myrtilloso-polytrichosa (9)		*Myrtillosa mel.* (13)		*Mercurialiosa mel.* (4)	
	AIC	*p*	AIC	*p*	AIC	*p*
Albic Arenosols (13)	–	–	–	–	–	–
Endogleyic Arenosols (5)	–	–	–	–	–	–
Ferralic Arenosols (7)	–	–	–	–	–	–
Hypoferralic Arenosols (5)	–	–	–	–	–	–
Rubic Arenosols (10)	–	–	–	–	–	–
Albic Podzols (7)	–	–	89	0.87	–	–
Histic Podzols (5)	–	–	88	0.87	–	–
Endogleyic Podzols (4)	–	–	88	0.87	–	–
Endogleyic Planosols (8)	67	0.62	85	0.28	–	–
Luvic Planosols (6)	–	–	87	0.72	–	–
Stagnic Cambisols (4)	66	0.62	88	0.87	–	–
Endogleyic Stagnosols (6)	63	0.12	–	–	37	0.11
Luvic Stagnosols (5)	–	–	88	0.87	36	0.11
Calcic Stagnosols (6)	–	–	–	–	37	0.11
Luvic Gleysols (6)	66	0.62	83	0.08	32	**0.01**
Stagnic Albeluvisols (4)	–	–	–	–	–	–
Cutanic Albeluvisols (7)	–	–	–	–	–	–
Endogleyic Luvisols (6)	–	–	–	–	–	–
Cutanic Luvisols (7)	–	–	–	–	–	–
Calcic Luvisols (7)	–	–	–	–	–	–
Endostagnic Luvisols (4)	–	–	–	–	–	–

n, number in sampling plots; – not found.

Table 9. Occurrence of tree species in sampling plots within different soil groups (IUSS Working Group WRB 2007)

Soil groups	Tree species (*n*)								
	Pine (67)	Spruce (69)	Birch (53)	Black alder (4)	Grey alder (6)	Ash (6)	Oak (21)	Aspen (8)	Acer (1)
Histosols	11	9	10	–	–	1	1	–	–
Gleysols	5	4	5	–	1	2	1	–	1
Stagnosols	2	9	8	–	1	1	4	2	–
Podzols	8	5	2	–	–	–	–	–	–
Cambisols	1	5	3	–	–	–	–	–	–
Albeluvisols	4	7	4	1	2	1	3	1	–
Luvisols	7	10	6	–	1	–	7	4	–
Planosols	5	9	8	3	–	–	–	–	–
Arenosols	22	8	4	–	–	–	4	1	–
Umbrisols	1	2	2	–	1	–	–	–	–
Phaeozems	1	1	1	–	–	1	1	–	–

n, occurrence in sampling plots; – not found.

(ash, black alder, grey alder, acer) were relatively poorly represented within the sampling sites. Only black alder was common on a specific soil group, Planosols, while other forest stand tree species within the sampling plots were distributed on different soils.

Generalized linear model analysis (Table 10) revealed a significant relationship ($p < 0.05$) between pine stands and Arenosols, spruce stands and Cambisols, and oak stands and the Luvisols soil group.

Overall, the generalized linear model approach suggests that there are weak significant relationships between the spatial distribution of soil groups and topographical situation and land cover.

DISCUSSION

Quaternary deposits, their granulometric and chemical composition have the highest bearing on the spatial distribution of soil groups. In Latvia, soils with sandy soil texture are mainly related to the Baltic Ice Lake and Litorina Sea, aeolian deposits, and glacioaquatic (glaciofluvial and glaciolacustrine) deposits, where Podzols and Arenosols are the dominant soils. The age of Quaternary deposits also plays a significant role in the spatial distribution of these soils. Although Podzols in the Latvian forest ecosystems are present in relatively different types of deposits, they are more closely associated with the Baltic Ice Lake deposits that are comparatively older (13 500–10 000 cal yr BP) (Gelumbauskaitė 2009) than the Litorina Sea (8800–6600 cal yr BP) (Raukas 1997; Saarse et al. 2006; Reintam et al. 2008) and aeolian sediments (Reintam et al. 2001). This conclusion coincides with the results of investigations carried out by Fransmeier et al. (1963) and Protz et al. (1984), which show that the full development of the Podzols profile in similar climatic conditions in Latvia occurred over a time period from 3000 to 10 000 years, just as in the U.S.A., Sweden, Finland and Norway (Lundström et al. 2000; Mokma et al. 2004; Sauer et al. 2008). In Latvia, Arenosols are predominant in the aeolian sediments that are relatively young. According to Nartišs et al. (2009), the age of even inland dunes is 6.4 to 11.9 OSL ka. Arenosols have a low cation exchange capacity (2.8–5.4 cmol kg^{-1}), which is a precondition for the relatively rapid development of the Spodic horizon (IUSS Working Group WRB 2007).

Luvisols and Albeluvisols are closely related to free carbonates containing glacigenic deposits (Table 2). The illuvial accumulation of clay on the vertical macro-aggregate surfaces of B horizons and formation of Argic diagnostic horizon were observed in these soils. The fundamental difference is the albeluvic tonguing between both soil groups that developed over a time period of 4600–6200 years (Sauer et al. 2009). Reintam (2002), Kühn (2003) and Sauer et al. (2009) emphasize the duration of the soil evolution process. In this case in Latvia, the age of the soil could not be the limiting factor in the evolution of Luvisols and Albeluvisols, because the age of these soils in all the sampling sites of forest ecosystems that developed on glacial till deposits exceeds 10 000 cal yr BP. The distribution of Luvisols, Albeluvisols and geological deposits is closely related to the mineral topsoil texture. Albeluvisols contain relatively more sand and less clay particles than Luvisols (Table 11). The topsoil horizon is acidic and has a

Table 10. Relationships between dominant tree species and soil groups (IUSS Working Group WRB 2007). The cases of significant relationships (the level of significance $p < 0.05$) are highlighted

Soil groups (*n*)	Tree species (*n*)							
	Pine (47)		Spruce (21)		Birch (22)		Oak (18)	
	AIC	*p*	AIC	*p*	AIC	*p*	AIC	*p*
Histosols (16)	159	0.97	113	0.98	117	0.88	105	0.90
Gleysols (8)	159	0.97	–	–	117	0.88	106	0.90
Stagnosols (12)	151	0.18	112	0.98	117	0.88	104	0.55
Podzols (9)	154	0.24	112	0.98	118	0.88	–	–
Cambisols (6)	157	0.80	105	**0.05**	118	0.88	–	–
Albeluvisols (9)	158	0.97	111	0.96	118	0.88	106	0.90
Luvisols (13)	155	0.40	112	0.98	–	–	97	**0.006**
Planosols (10)	153	0.25	110	0.48	113	0.16	–	–
Arenosols (25)	141	**0.0004**	–	–	111	0.28	106	0.90

n, number in sampling plots; – not found.

Table 11. Average particle size distribution and chemical characteristics of the mineral topsoil layers of Albeluvisols and Luvisols (IUSS Working Group WRB 2007)

Soil group (layer depth)	Clay, %	Silt, %	Sand, %	PH ($CaCl_2$)	Cation exchange capacity, cmol kg^{-1}
Albeluvisols (0–20 cm)	5.96	27.64	66.43	4.18	15.23
Albeluvisols (20–40 cm)	12.08	29.55	58.39	5.12	10.33
Luvisols (0–20 cm)	17.82	34.90	47.27	4.63	27.58
Luvisols (20–40 cm)	33.34	35.49	31.18	5.63	21.60

lower cation exchange capacity, which confirms that the decarbonatization process is an important factor in the development of Albeluvisols (Kühn 2003; Sauer et al. 2008). We agree with Reintam (2002) that in Latvia, similarly to Estonia, the Albic horizon that can be formed either as a result of lessivage, podzolization or reductomorphic processes is characteristic of Albeluvisols. In the forest ecosystems of Latvia, a weakly expressed podzolization process that morphologically becomes apparent as the E horizon, which diagnostically mismatches the Albic horizon, is only occasionally observed in Luvisols.

Significant relationships between Gleysols, Planosols and glaciolacustrine deposits (Table 11) is determined by the soil texture and relatively flat topography. A heavy soil texture (clay, silty clay, sandy clay loam) affects the development of seasonal reducing conditions and the stagnic colour pattern within the soil profile. Lithological discontinuity, which is the criterion for the determination of Planosols, is characteristic of most of the glaciolacustrine deposits.

The most essential factor for vegetation is soil, the parameter expressing the development potential of plant communities (Kõlli & Ellermäe 2001). The forest soil research in Latvia showed that spatial distribution relationships do not always exist between forest site types and soil groups, and prefix qualifiers according to the international FAO WRB soil classification (Tables 5–8). In forest ecosystems on dry mineral soil, *Cladinoso-callunosa*, *Vacciniosa* and *Myrtillosa* are closely related to the nutrient-poor Arenosols, *Aegopodiosa* has significant relationships to the nutrient-rich Luvisols and the mesotrophic *Hylocomiosa* forest site type is related to Albeluvisols. Similar relationships were observed also in Estonia, where soil texture and soil productivity determine the distribution of the vegetation site type and nutrient-poor soils have good correlation with vegetation site types (Palo 2005). Forest site types on wet peat and drained peat soil are related to Histosols, because, as already described before, their determination criteria are similar. Assessing the relation of the spatial distribution of soils with the forest stand composition and forest site types, one should take into account that forest stands in different stages, forming due to the overgrowing of agricultural lands and clearings, can often be found in Latvian forests. As a result, a very different stand composition may develop on soils of the same kind (Ruskule et al. in press) and higher correlation develops only when ecosystems reach their climax stage. The planting of homogeneous spruce monocultures in the 1960s (Laiviņš 1998), when, notwithstanding the soil texture and territory drainage, the Latvian forests were renewed by planting spruce, has an equally important effect on the disparity between soils and forest stand composition in Latvia.

Estimating the interrelationships between the prefix qualifiers of soil groups and forest site types, in most cases we found a significant relationship between soil groups and prefix qualifiers in dry forest site types *Vacciniosa*, *Myrtillosa* and *Aegopodiosa*. This can be explained by the fact that the complex of prefix qualifiers of soil groups is used for characterizing one specific soil. For instance, in the *Myrtillosa* forest site type, the most characteristic soils are Ferralic Hypoferralic Endogleyic Rubic Albic Arenosols, and *Aegopodiosa*, in most cases, occurs on Luvic Calcic Endogleyic Stagnosols and Calcic Endostagnic Endogleyic Luvisols.

The spatial distribution of the mesotrophic *Hylocomiosa* and eutrophic *Oxalidosa* forest site types is closely related to the relatively high diversity of soil groups and their prefix qualifiers. Therefore, there are more variation options, and the current data are insufficient to establish specific interrelationships of impact.

The importance of the diversity of soil groups and prefix qualifiers is also reflected in the analysis of interrelationships between tree species, Land Cover classes and soil groups. With the generality increase of a vegetation characteristics unit (forest site type → dominant tree species in a forest stand → Land Cover class), a decrease in interrelationships between the vegetation characteristic type and soil group and their prefix qualifiers was observed. Better interrelationships could be provided by the improvement of biotic environment information.

In general, the study showed that there is always no close relationship between vegetation types and soils.

Therefore, it is very difficult to make predictions with regard to the future vegetation on the basis of the relationships between soils and the vegetation type (Palo et al. 2005; Uuemaa et al. 2008). Hence, according to the international FAO WRB soil classification, it is difficult to use soil information in the boreo-nemorial region, where the soil parent material has varying soil texture formed by glacial melting water and glacial deposits, for the prediction of potential soil, vegetation and forest site types.

CONCLUSIONS

The study results show that it is possible to determine the relationships between the distribution of basic soil groups and environmental factors, using the generalized linear models of data statistical analysis provided by the *R 2.11.1* software.

This study has shown that a very high diversity of soil groups exists in lithologically similar Quaternary deposits. Furthermore, several forest site types are related to most soil groups, depending on the parent material, location and moisture conditions.

On the one hand, the solutions for the acquisition of information on Quaternary deposits and forest spatial distribution in Latvia proposed in this article might facilitate soil mapping on a regional scale in the future. On the other hand, to concede, the information given hereinabove cannot improve large-scale soil mapping. Therefore, detailed investigations on the changes of soil morphology and soil properties in catene, also depending on soil texture, are due. In any case, taking geological contours as a basis, it is possible to single out soil group associations in soil mapping, although it is difficult to single out separate soil groups.

Determining the existing relationships facilitates the future mapping of the boreo-nemorial region soils that have formed mainly on the Late Weichselian Glacial deposits, altered by postglacial aeolian, marine, lacustrine, alluvial and mire sediments (on a regional scale of 1 : 50 000, because information on the spatial distribution of geological sediments and forest site types is available on this scale and it is a standard scale in Latvia).

The study results show that, in perspective, it would be necessary to continue studies, clarifying the strengths and weaknesses of the FAO WRB soil classification and its application in the research of forest ecosystems.

The relationships of drained and undrained soils with environmental factors have been ascertained. It was found that the impact of environmental conditions on ameliorated soils is reflected in forest site types, not in the soil profile according to the FAO WRB soil classification.

Acknowledgements. This research was supported by the ICP Forest monitoring and Forest Focus research programme International project ‘Inventarization of forest soils and assessment of forest biological diversity “BioSoil”’. We thank Andis Lazdins for his helpful comments. We are grateful to Dr Guntis Brumelis, Dr Didzis Elferts, the University of Latvia Faculty of Biology, also to Dr Guntis Tabors and Ingus Liepins of the University of Latvia, who assisted in the fieldwork, our colleague from the University of Amsterdam, the Netherlands, Dr Pieter Dirk Jungerius for helpful review of earlier drafts and to two anonymous reviewers for their instructive comments.

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Keskkonnategurite mõju metsamuldade ruumilisele levikule ja mitmekesisusele Lätis

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Töö eesmärgiks oli kindlaks teha vastastikused levikupõhised seosed keskkonnategurite (kvaternaarsed setted, topograafiline situatsioon, maakate, metsakasvukohatüüp, puu liik, mulla lõimis) ja mullagruppide ning nende eesliitega (prefiks) täpsustatud tunnuste (kvalifikaatorite) vahel. Töös uuritud kvalifikaatorid määrati WRB (World Reference Base for Soil Resources) 2007. aasta IUSS-i töögrupi väljaande põhjal (2006. aasta väljaande korrigeeritud versioon). Töö tulemused näitasid, et üldistatud lineaarsete mudelite abil on võimalik kindlaks teha (selgitada) keskkonnategurite ja mullagruppide leviku mustri vahel esinevaid vastastikuseid seoseid. Läti 113 metsaprooviala andmete põhjal koostatud andmebaaside statistilisel analüüsil kasutati *R 2.11.1* tarkvara. Tööst ilmnes, et suhteliselt sarnase geoloogiaga (geoloogilise päritoluga) aladel võib mullastik vägagi mitmekesine olla. Uurimine näitas, et erinevatel põhjustel ei täheldatud tihedat seost mullagruppide ja nende eesliidete abil detailiseeritud tunnuste ning kvaternaarsete setete vahel ega ka tunnuste alusel detailiseeritud mullagruppide ja metsakasvukohatüüpide ning peapuuliikide vahel. Tihedas korrelatiivses seoses on kvaternaarsed setted, metsakasvukohatüübid ja peapuuliigid vaid toitainevaestel setetel ning vabu karbonaate sisaldavatel toitainerikastel setetel kujunenud mullagruppidega. Olulist korrelatiivset seost ei täheldatud aga CORINE maakatte klasside, topograafilise situatsiooni ja mullagruppide vahel. Töös selgitatud seosed on suureks abiks regionaalsete (1 : 50 000) mullastikukaartide koostamisel.